

XXIII. *On the ultimate composition of simple alimentary substances; with some preliminary remarks on the analysis of organized bodies in general.* By WILLIAM PROUT, M. D. F. R. S.

Read June 14, 1827.

THE present being the first of several communications on the same subject which I hope to have the honour of laying before the Royal Society, a few observations on the origin and object of the whole series may not be deemed irrelevant.

Many years ago I published an anonymous Paper, containing some views, at that time new, connected with the doctrines of chemical proportions.* Though this Paper, for reasons which need not be here stated, was drawn up and published in a very hasty and imperfect manner, it attracted some notice; and the views therein advanced gradually gained ground, and at present appear to be generally admitted in this country.† When this Paper was published, it was my intention to have pursued the subject further, but I soon found my progress obstructed by insuperable difficulties. The first and chief of these was the want of accurate data; and the infinity of objects comprehended by chemistry prevented the hope of acquiring, by individual exertion,

* Annals of Philosophy, vi. 321, and vii. 111. (O. S.) The object of the second Paper was simply to correct some oversights in the first.

† Dr. THOMSON'S Chemistry, and his Attempt to establish the first principles of chemistry by experiment. Also, Dr. HENRY and Mr. BRANDE'S Elements of Chemistry, &c.

however unremitting, a sufficiency for the establishment of general laws. Professional duties still further limited my exertions, and at length obliged me to relinquish chemistry in general, and confine my attention solely to the chemistry of organized substances; a subject that has occupied the greater portion of my leisure hours for the last ten or twelve years.

Organic chemistry is confessedly one of the most difficult departments of the science; and though much has been done, and more attempted on the subject, it is yet in a very imperfect and unsatisfactory state; and it must be frankly admitted that Physiology and Pathology have derived less advantage from this most promising and really powerful of the auxiliary sciences, than might have been expected. To explain this perhaps would not be difficult; but as the explanation would be misplaced here, I shall merely observe, that dissatisfied with the old modes of inquiry, I determined to attempt a different one, and keeping in view the notions I had originally formed respecting chemical combinations, proposed to myself to investigate the modes in which the three or four elementary substances entering into the composition of organized bodies are associated, so as to constitute the infinite variety occurring in nature.

With these views my first object was to determine the exact composition of the most simple and best defined organic compounds, such as sugar, and the vegetable acids, a point that had been several times before attempted, but, as it appeared to me, without complete success. About the same time also albumen and other animal products, as urea, lithic acid, &c. were examined with similar views. The subject

of digestion, however, had for a long time occupied my particular attention; and by degrees I had come to the conclusion, that the principal alimentary matters employed by man, and the more perfect animals, might be reduced to three great classes, namely, the *saccharine*, the *oily*, and the *albuminous*: hence, it was determined to investigate these in the first place, and their exact composition being ascertained, to inquire afterwards into the changes induced in them by the action of the stomach and other organs during the subsequent processes of assimilation. In conformity with this plan, the object of the present communication is the consideration of the first class or family above-mentioned, namely, the *saccharine*.

Preliminary observations on the analysis of organised substances.

Vegetable substances contain at least two elements, hydrogen and carbon; and most generally three, hydrogen, carbon, and oxygen. Animal substances are still more complicated; and besides the above three, usually involve a fourth element, namely, azote, to which they appear to owe many of their peculiar properties. These general facts have been known ever since the elements themselves have been recognised as distinct principles, though the determination of the exact proportions in which they enter into any particular substance, has always proved a most difficult problem. To enumerate all that has been done on this subject would be loss of time; and it need only be mentioned, that all idea of separating the different elements from one another, so as to obtain them *per se*, has been long since abandoned, if indeed

it was ever entertained, and the general principle on which the analysis of organic products has been usually conducted, has been to obtain their elements in the form of binary compounds, either by destructive distillation, as was formerly practised; or by combining the elements with some other element with which they possessed the property of forming definite binary compounds, from the quantity and known composition of which, those of the original elements might be readily obtained by calculation. For this latter purpose oxygen has been the principle usually employed, which, as is well known, forms water with hydrogen, and carbonic acid gas with carbon; two compounds not only as well understood as any in chemistry, but likewise, from their physical properties, well adapted for the purpose. When azote is involved other means must be adopted, which will be fully considered hereafter.

The modes in which chemists have attempted to combine oxygen with the hydrogen and carbon of vegetable substances have differed very considerably. The illustrious LAVOISIER attempted their union by burning the substance at once in oxygen gas, a method subsequently followed by SAUSSURE and others. Afterwards the metallic oxides were employed for the purpose; and BERZELIUS in particular informs us, that so early as 1807 he had tried the oxide of lead, but did not succeed with it.* In 1811, GAY LUSSAC and THENARD published the analysis of different organic substances made by means of the chlorate of potash; and, considering the nature of the apparatus they employed, they obtained admirable approximate results.† BERZELIUS, in 1814, published an

* *Annals of Philosophy*, iv. 403.

† *Recherches Physico-chimiques*, ii. 265.

elaborate paper on the subject of vegetable analysis, in which he likewise employed the chlorate of potash, but in quite a different manner ; and to this celebrated chemist I believe we are indebted for the improvement subsequently adopted by most of his successors, of introducing the mixture of the substance to be analysed, and the oxide, into a narrow tube, and submitting the different portions of it to heat in succession. The results of BERZELIUS were in general more accurate than those of his predecessors, especially as far as related to the quantity of carbon, but his method was not well adapted for determining the proportion of hydrogen.* In 1816, GAY LUSSAC seems to have thought of employing the oxide of copper for the purposes of analysis,† the introduction of which undoubtedly constituted one of the greatest improvements hitherto made in organic analysis ; and the use of which has continued to the present time, and will perhaps never be entirely superseded. The oxide of copper has however some disadvantages, which it is one object of the present remarks to point out ; another is, to propose a form of apparatus free from most of the objections to which those hitherto in use have been more or less liable.

There are two methods of arriving at the quantity of water formed during the combustion of an organized substance ; either actually to collect and weigh it, as BERZELIUS did, or to estimate the quantity by the loss of weight sustained by the tube after the combustion. The latter in general is the best method, and was that adopted by me from the first : it has since been followed by Dr. URE, and others.‡ Whichever

* *Annals of Philosophy*, iv. 323.

† *Annales de Chimie*, xcvi. 306.

‡ *Phil. Trans.* 1822. p. 457.

method is adopted, it obviously becomes necessary that no extraneous water be present ; but all pulverulent substances, and oxide of copper among the rest, are more or less hygrometric, and rapidly attract moisture from the atmosphere. This circumstance seems to have struck the French chemists, and it occurred to me at a very early period. Dr. URE, however, was the first who published a method of obviating this difficulty ; and his method, if this were the only difficulty to contend with, is capable of considerable precision. But there is another, and perhaps still more troublesome property, possessed by the oxide of copper, in common with many other powders, namely, that of condensing air as well as water ;* and these two difficulties, taken together in conjunction with another mentioned in a note below, render great precision almost out of the question.† To conquer these,

* See SAUSSURE's paper on the absorption of the gases by different bodies. *Annals of Philosophy*, vi. 241. Also GILBERT's *Annalen der Physick*, xlvii. 112.

† As I am unwilling that so much labour should be lost, particularly as it may be of some use to other inquirers, I have thrown into the form of a note a few of the principal circumstances connected with the inquiry mentioned in the text. In my earlier experiments tubes of iron, copper, &c. were employed instead of glass, and charcoal instead of spirits, as the medium of heat ; and during this period most of the modifications of apparatus which have been since proposed as novelties or improvements, were tried and rejected. I first took the hint of employing a spirit lamp from Mr. PORRETT, and was certainly among the first that did so employ it. Various forms of lamps were tried, but at length I was induced to relinquish the use of the horizontal apparatus for the vertical one ;‡ and this, I have no hesitation in saying, is by far the best form of apparatus hitherto proposed for the substances to which it is adapted ; nor would any other have been required by me, at least, had it not been for the properties of the oxide of copper alluded to in the text, which render this and all other forms of apparatus depending on the

‡ Described in the *Annals of Philosophy*, xv. 190 (O. S.) and more completely in Dr. HENRY's *Chemistry*, ii. 167, ninth edition.

every means that could be thought of, as likely to succeed, were tried, but without effect, and I was obliged to relinquish

employment alone of that substance perfectly useless when great accuracy is required. It has been objected to the lamp that the heat produced by it is not sufficient; but this is a mistake; at least I have never met with any substance that resisted its action, provided the oxide of copper was well shaken up in the tube, or, if necessary, taken out of the tube and retrituated, and afterwards exposed to heat a second time, one or other of which *ought to be done in all instances*, whatever be the medium of heat employed; for no ordinary heat will induce the oxide to part with its oxygen to a combustible substance at some distance off, and not immediately in contact with itself. A great heat is also attended with some disadvantages, and among others, that of causing the oxide to adhere together in hard and solid masses, which thus becomes more difficult to be removed from the tube, and much less adapted for future experiments. In general organized bodies are more difficult of combustion, and require more heat than crystallized ones. The lamp described in the text I have only recently employed, and it answers the purpose in all respects better than any I have yet seen.

With respect to the sources of error above mentioned, it was found that 200 grs. of the oxide of copper, recently ignited, gained, after ten or fifteen minutes exposure to the air, a quantity varying from .02 to .05 gr. one half of which, or even more, was acquired before it became cold; that is to say before it had cooled down to 100°, considerably above which point it began to acquire weight. Of the increase of weight above mentioned, it was found that about $\frac{1}{3}$, or $\frac{1}{4}$, (for the proportion varied from causes that I could not discover) was due to the condensation of air, the rest was due to moisture. The oxide I employed was perfectly pure, and prepared by exposing metallic copper to heat. Dr. URE states, "that 100 grs. of the oxide prepared from the nitrate of copper exposed to a red heat merely till the vapours of nitric acid were expelled, absorbed in the ordinary state of the atmosphere from .1 to .2 gr. in the space of an hour or two, and about half that quantity in a very few minutes."

In determining the quantity of water formed by the oxide of copper in the usual manner, there is yet another difficulty to contend with, to which we have alluded above, and which we shall here briefly notice. It has been stated, that complete combustion seldom or never takes place during one exposure to heat, and that in many cases the oxide ought to be removed from the tube and retrituated. Now it was found, almost invariably, that during the second exposure to heat, the tube, instead of *losing* additional weight, actually became *heavier*, sometimes to the

the matter in despair, and endeavour to contrive some other mode of analysis that should be free from these difficulties altogether. After a good deal of consideration I was induced to adopt a method which had occurred to me long before, but which I had never put in execution. This method is very simple, and founded on the following well known principles.

When an organic product containing three elements, hydrogen, carbon, and oxygen, is burnt in oxygen gas, one of three things must happen. 1. The original bulk of the oxygen gas *may remain the same*, in which case *the hydrogen and oxygen in the substance must exist in it in the same proportions in which they exist in water*; (for it is well known that oxygen gas by being converted into carbonic acid gas is not altered in its bulk): or, 2. The original bulk of the oxygen may be *increased*, in which case the oxygen must exist in the substance in a *greater* proportion than it exists in water; or, 3. The original bulk of the oxygen gas may be *diminished*, in which case the *hydrogen must predominate*.

Hence it is obvious, that in the first of these cases the composition of a substance may be determined by simply ascertaining the quantity of carbonic acid gas yielded by a known quantity of it; while in the other two, the same can be readily ascertained by means of the same data, and by noting the excess or diminution of the original bulk of the oxygen gas employed. Such are the simple and universally admitted

amount of $\cdot 03$ gr. though often much less than this. I was a good deal puzzled to account for this anomaly at first, but believe that it arose chiefly from the reoxidation of the partially reduced oxide, by the air of the atmosphere.

Since this Paper was read before the Royal Society, I have observed one or two other singular facts connected with this subject, which will be noticed when we come to speak of the analysis of substances containing azote.

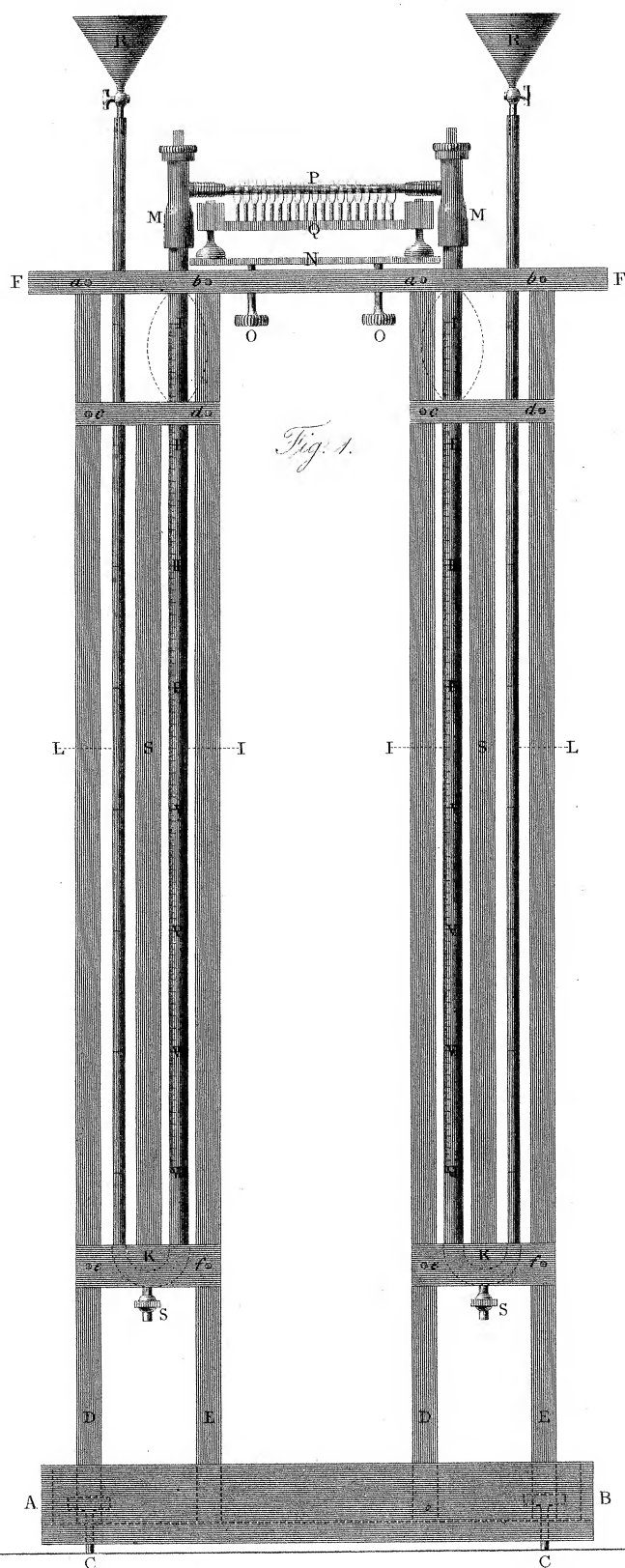


Fig. 1.

Feet

principles in which the following method of analysis is founded ; the only novelty in which, therefore, is the form of the apparatus ; and of this it is hoped the following summary sketch, and annexed figures, will convey every requisite information.

Fig. 1, Plate XIV, represents a front view or elevation of the whole apparatus in the act of being employed. AB is a platform, two feet square, surrounded by a ledge about $2\frac{1}{2}$ inches high, for preserving any mercury that may chance to fall about, and furnished with four adjusting screws (of which two, CC, are sectional views), by means of which it may be placed perfectly horizontal. Into this platform, in the manner represented, are fixed perpendicularly four square pillars, DE, DE, about four feet and a half high, at the top of which is placed another small platform, FF, about four inches wide, and which may be fixed or removed at pleasure by means of the brass pins *a b*, *a b*. II are glass tubes graduated with the utmost care to hundredths of a cubic inch, and which are cemented at bottom into semicircular iron tubes enclosed in the blocks KK (as represented by the dotted lines). These iron tubes project a little below the wood at the lower part, where they are furnished with iron stop-cocks, SS, for drawing off the mercury when it may be necessary. Into the other end of these semicircular tubes are likewise cemented the glass tubes LL (of smaller dimensions, and a little longer than the tubes II), and forming with them, when taken together, inverted syphons. The smaller tubes, LL, are represented as surmounted by funnels, RR, furnished with stop-cocks, the object of which is to permit the mercury to flow into them with any velocity that may be required. On the

tops of the larger tubes, II, are cemented the vertical stop-cocks, MM, of which fig. 2. Plate XV, is a sectional view on a larger scale, and which renders the construction so obvious, that perhaps no further remark is necessary, than merely stating that the cup, *a*, is filled with oil, and that the plug, *b*, which is square at the upper part, and adapted to a key, is furnished with a shoulder, on which the screw-cap, *c*, rests, and by means of which it may be tightened at pleasure.*

On the platform, FF. (fig. 1.) is a thin piece of wood, capable of being raised or depressed at pleasure, by means of the screws, OO; on this the lamp Q is placed, which may thus be placed at any distance that may be required from the tube, P. Fig. 3, is an enlarged view of this lamp: it consists of two reservoirs, *de*, for holding the spirit, connected together by means of the tube, *f*, into which are placed, at the distance from one another of about $\frac{1}{3}$ of an inch, a number of vertical burners, *g g*, &c. about $\frac{1}{12}$ of an inch in diameter, and $\frac{3}{4}$ inch long, and *made as thin* as possible, with the view of preventing the conduction of the heat. These burners are each furnished with a few threads of cotton, and are bent a little alternately like the teeth of a saw, in order that their flame may envelope the tube, P, (fig. 1.) more completely. *h* is a cover for the wick of the lamp when not in use. The

* These syphons are fixed together independently of the general frame work, and may be removed at pleasure by taking out the pins *c d*, *c d*, and *e f*, *e f*. This admits of their being replaced by others of different sizes. Those of a larger size have balls near the top, as represented by the dotted lines, and may contain as much as 20 cubic inches of gas. It much facilitates the process of determining the exact quantity of gas contained in the apparatus, to have both legs of the syphon graduated, which may be easily done so as to obviate the effects of capillary attraction when the tubes are not both of the same calibre.

Fig. 2.

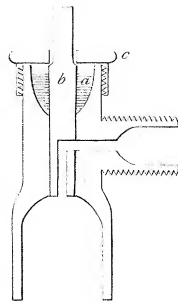


Fig. 3.

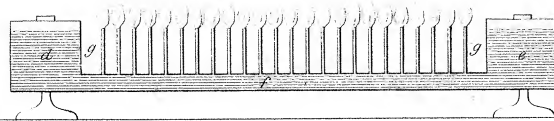
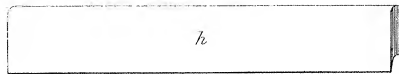


Fig. 5.

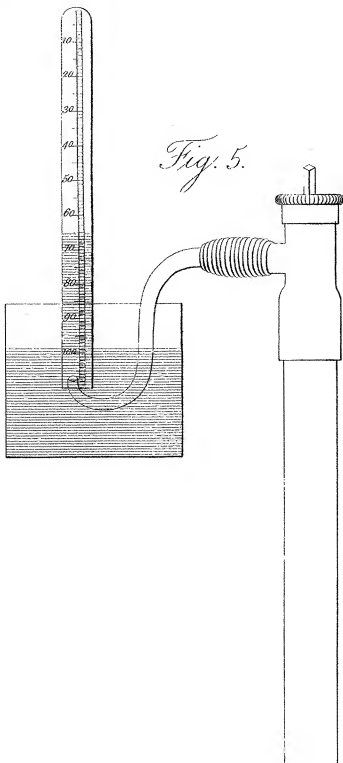
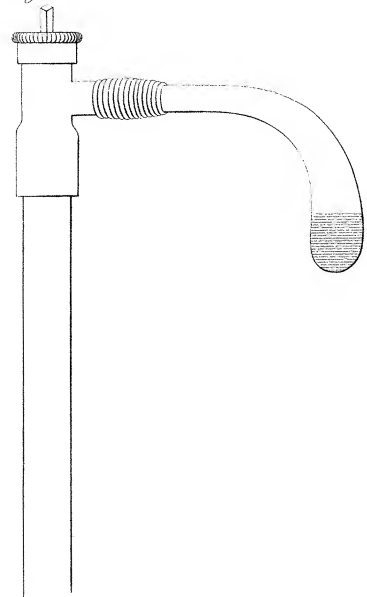


Fig. 4.



tube, P, (fig. 1.) is of green or bottle glass, moderately stout, and about $\frac{1}{3}$ of an inch internal diameter. It is fixed between the horizontal parts of the vertical cocks, M M, so as to be perfectly air-tight; and when required, the whole, or any part of it, may be heated by means of the lamp, Q, at the pleasure of the operator.

When the apparatus is to be employed, both the syphon gasometers, I L, I L, are to be filled with quicksilver, and a small green glass retort, containing the requisite quantity of chlorate of potash, (and which had been previously heated so as to completely expel the common air, and to fill it with oxygen gas) is to be attached to one of the cocks, as represented in fig. 4, by means of a caoutchouc tube. Heat is then to be applied, and any quantity of oxygen gas that may be required, introduced into the tube, I. After the whole has acquired the temperature of the atmosphere, the exact quantity of the gas is to be accurately noticed, as well as the state of the barometer and thermometer at the same time. The tube, P, containing the substance to be analysed, is then to be firmly fixed between the cocks M M,* and subjected to heat, during which the oxygen gas is to be transferred from one syphon to another, through the red hot tube, with any velocity that may be required, and which may be regulated by means of one of the stop-cocks of the funnels, R R, and the stop-cock, S, of the opposite syphon.

Such is a general view of the apparatus, and the principles

* I have tried various modes of connecting the tube so as to ensure its being air-tight. Caoutchouc answers very well; but the best substance I have hitherto employed are slips of thin moistened hogs' bladder, tied on very tightly with fine dry twine. The twine is then to be moistened also, and the whole kept in this state till the end of the experiment.

of its operation; but perhaps a few practical remarks on some of the circumstances to be attended to during its employment, may not be deemed superfluous.

The substance to be analysed may be placed in a small tray made of platina foil, and introduced alone into the tube P, and gradually submitted to the action of heat and oxygen gas; but this does not answer well with organic compounds, as a portion of them is apt to escape combustion. Another method is to mix the substance with pure silicious sand, and to retain the mixture in the centre of the tube by means of asbestos. But this method often fails, except there be about an inch of the oxide of copper at each end of the tube, which must be kept red hot during the experiment, and in this case it succeeds completely with many substances. Another method, and that which the most generally succeeds, is to mix the substance with peroxide of copper, to heat these together in the tube in the first place, and afterwards to open the other stop-cock and send the oxygen gas through the ignited and partially reduced oxide, by means of which it again becomes peroxidized; and any portion of the substance that had escaped complete combustion in the first part of the experiment, is now completely burnt. This last method is also that employed when it is required to determine the quantity of carbonic acid gas yielded by a given quantity of any substance; only in this case, of course, oxygen gas is not required, and the contents of the tube P, must be taken out and well triturated, and subjected to heat a second time. If it should be required to analyse the gas formed, one method of removing it from the tube I, is represented at Fig. 5; and others will readily occur to the practical chemist.

The following are some of the advantages of this appa-

ratus, and mode of analysing organic compounds. In the first and chief place, *there is nothing to be apprehended from moisture*. Whether the substance to be analysed be naturally a hydrate, or in whatever state it may be with respect to water, the results will not be affected; and the great problem, whether the hydrogen and oxygen exist in the substance in the proportions in which they form water, or whether the hydrogen or oxygen predominates, will be equally satisfactorily solved, and that (of course within certain limits), independently of the weight of the substance operated on.* When however it is the object to ascertain the quantities of carbonic acid gas and water yielded by a substance, it is, of course, necessary to operate on a known weight; but this being once determined, there is no fear, as in the common methods, of exposing the substance to the atmosphere as long as may be necessary. The hygrometric properties of the oxide of copper, as well as its property of condensing air, are also completely neutralised, for the whole, at the end of the experiment, being left precisely in the same state as it was at the commencement, the same condensation of course must take place, and any little differences that may exist are rendered quite unimportant from the bulk of oxygen gas operated on, which of course should, in all instances, be considerably greater than that of the carbonic acid gas formed. Another advantage of this method is, that more perfect combustion is ensured by it than by any other that I am acquainted

* It is to be observed, that, throughout the experiments, great care is taken that the gases are *saturated with moisture*; the errors from this cause are thus rendered definite, and are easily corrected by tables calculated for the purpose from the most accurate data, and which will be given in a subsequent communication.

with. There is also no trouble of collecting or estimating the quantity of water, a part of the common process attended with much trouble, and liable to innumerable accidental errors, besides those already mentioned, and which there is no method of obviating or appreciating; here, on the contrary, the results are obtained in an obvious and permanent form, and, from the ease with which they are thus verified, comparatively very little subject to error.

It need scarcely be stated, that the form and principles of this apparatus render it well adapted for many other chemical operations besides the analysis of organized substances. Such, for example, as the reduction of oxides by hydrogen, and a variety of others that will readily occur to the practical chemist.

Of the Saccharine principle.

In the following observations, the word *Sugar*, is used in its ordinary acceptation; but the extended sense in which the term *saccharine principle* is employed, requires a few remarks.

Messrs. GAY LUSSAC and THENARD were induced to conclude, from their experiments on organized products, that when the hydrogen and oxygen of a substance exist in it in the proportions in which they form water, the substance is neither acid nor alkaline, as in sugar, starch, gum, &c.; that when the oxygen exceeds this proportion, the substance possesses acid properties; that when it is less, an oily or resinous character.* These conclusions are true to a certain extent, but by no means universally so, as will be shown hereafter. I shall however adopt this general distribution of

* Recherches Physico-chimiques. ii. 321.

organized substances so far, as to confine my attention at present to those substances in which the first peculiarity above mentioned exists; and as sugar, on account of its crystalline form, appears to constitute the most perfect and definite of these substances, I have thought it best entitled to give a name to the whole class, or family, and hence have included, under the term *saccharine principle*, all those substances, whatever their sensible properties may be, into the composition of which the hydrogen and oxygen enter in the proportions in which they form water. Now it will be found, that the substances thus constituted may generally be employed as aliments, and as they are chiefly derived from the vegetable kingdom, they may be considered as representing vegetable aliments, properly so called; hence, *saccharine principle* and *vegetable aliment* may be regarded as synonymous terms, and they will be so employed throughout the present inquiry.

As a subject of general interest to chemists, as well as of considerable importance in the present inquiry, I shall also attempt to investigate the composition of a few of the compounds of the saccharine principle with oxygen, or what are usually denominated the *vegetable acids*.

Of Sugars.

Many analyses of sugar have been published by different chemists, no two of which agree with each other. These discrepancies have doubtless arisen from various causes, though one cause has probably been some real or accidental difference in the composition of the sugars employed.* How

* Some years ago I published an analysis of sugar, in which the proportions of carbon to water were stated to be to one another as 40 : 60. I was not aware at

many distinct varieties of sugar exist I do not pretend to know, but there are at least two, (independently of the sugar of milk, manna, &c. which belong to another series), and probably there are several others; and it is to the mixture or combination of these in different proportions, and the frequent presence of foreign bodies, that a good deal of the confusion respecting the composition of sugar has undoubtedly risen.

Cane Sugar. The strongest and most perfect sugar that I am acquainted with, is sugar candy carefully prepared from cane sugar. This, purified by repeated crystallizations from water and alcohol, and deprived of the little hygrometric

that time of the differences existing among sugars, and the results given were founded on the analysis of a specimen of remarkably fine looking sugar candy, a quantity of which I had purchased and kept by me for several years for the purposes of experiment.† At length my stock became exhausted, and I was surprised to find on analysing other specimens, that they in general contained upwards of one per cent. more of carbon than what I had before examined. This induced me to recur to the notes of my former experiments, but I could detect no material error in them; and though I readily admit that the apparatus I then employed was much less susceptible of accuracy than what I now use, I cannot help thinking that the candy itself was partly in fault, and that it was prepared from an imperfect sugar, probably from the East Indies.

There was also another circumstance which contributed to mislead me, not only in this but in all my other results, viz. an inaccuracy in the weight usually assigned to atmospheric air, at least as regarded *my weights*. I have long suspected the perfect accuracy of this datum as settled fifty years ago by Sir G. SHUCKBURGH, and have been accustomed for some time past to make an allowance for it; but I was not aware till recently of its exact amount, when I was induced to undertake a series of experiments on the subject, which I hope shortly to lay before the public.

† See Annals of Philosophy, iv. 424 (N.S.) I do not distinctly remember whether, at the time this paper was published, some of the original sugar candy existed or not, but I had then only made one or two experiments on the sugar of commerce.

moisture that usually adheres to it by exposure for some time to a temperature of 212° , was found to be composed of

Carbon	-	-	-	42.85
Water	-	-	-	57.15

Now, all the finest and purest specimens of loaf sugar of commerce that I have yet examined, give, when similarly treated, precisely the same results. They may therefore be considered as identical in their composition with sugar candy.* Cane sugar appears to undergo no change whatever at the temperature of boiling water; but at about 300° it begins to melt, and assume the form of a dark brown liquid. In one experiment, after exposure to this temperature for seven hours, it lost .6 per cent. only of its weight, but its properties seem to have been permanently injured. BERZELIUS however has shewn that, on being combined with lead, sugar parts with about 5.3 per cent. of water without undergoing decomposition; for he has likewise shown that it may be obtained again from the lead in its original state. This saccharate of lead I have several times formed, and once by accident I obtained it in the state of beautiful crystals.

Sugar of Honey. The lowest† well defined sugar that I have yet examined, was first obtained from Narbonne honey, by means of a process formerly pointed out by me for obtain-

* Dr. URE states that he has found sugar to contain upwards of 43 per cent. of carbon; but no such specimen has occurred to me, though I by no means deny its existence. Indeed I have hitherto met with no sugar as it occurs in commerce, yielding more than 42.5 per cent of carbon, and frequently it contains considerably less than this.

† In commerce, these imperfect sugars are denominated *weak* or *low* sugars, which last epithet is here employed in this sense.

ing diabetic sugar in a state of purity.* This, deprived of its hygrometric moisture by being placed under a receiver with sulphuric acid for several days, was found to consist of

Carbon - - - 36·36

Water - - - 63·63

This sugar in the ordinary state of the atmosphere usually contains more water than indicated by this analysis ; that is to say, generally about 64·7 per cent. On the other hand, on exposure to a temperature considerably below that of boiling water, it rapidly loses about 3 per cent. of water, and begins to assume the fluid form ; kept at the temperature of boiling water for 30 hours, it lost in one experiment upwards of 10 per cent. of its original weight, became of a deep brown colour, and seemed to be partially decomposed.†

Sugar prepared from *starch* evidently belongs to this variety, as is sufficiently indicated both by its sensible properties and composition. The same is true in general of *diabetic sugar*, and probably also of the *sugar of grapes, figs, &c.* When pure, all the varieties of this sugar are beautifully

* Med. Chirurg. Trans. viii. 537. I have little doubt that honey contains a still lower sugar, and which is incapable in this country (at least during a great part of the year), of assuming the solid form. This is probably the liquid sugar of PROUT.

† I observed that after this sugar had been cautiously melted it might be preserved in the state of a transparent fluid, if placed in a perfectly dry atmosphere, as under the receiver of an air pump with sulphuric acid ; but that in a few hours after exposure to the air, it began to grow opaque and assume the crystalline form, by attracting moisture. Is not this precisely analogous to the deterioration which is known to take place in the sugars of commerce? See Mr. DANIELL on this subject in the Royal Institution Journal, v. 32. Dr. URE supposes that this deterioration depends on the absorption of oxygen ; but I have hitherto met with no sugar containing an excess of oxygen.

white, crystallize in spherules, and are permanent under the ordinary circumstances of the atmosphere.

Between these two extremes, sugars occur of almost every grade, as the following table will show.

	Carbon.	Water.
Pure sugar candy - - -	42·85	57·15
* Impure sugar candy	41·5 to 42·5	58·5 to 57·5
East India sugar candy (v)	41·9	58·1
English refined sugar	41·5 to 42·5	58·5 to 57·5
East India refined sugar (v)	42·2	57·8
Maple sugar (v) - - -	42·1	57·9
Beet-root sugar (v) - -	42·1	57·9
East India moist sugar (v)	40·88	59·12
Sugar of diabetic urine -	36 to 40?	64 to 60?
Sugar of Narbonne honey	36·36	63·63
Sugar from starch - - -	36·2	63·8

On some of these it may be necessary to make a few remarks. The *sugar candies* of the shops frequently contain minute quantities of foreign fixed bodies, such as lime, &c., as well as others of a destructible character. Both the specimens of *India sugar candy* I examined were obviously impure to the eye, being of a brown colour and deliquescent; they contained, among other things, traces of potash. The *East India refined sugar* was perfectly white, but rather soft and friable, and it did not possess the fine and brilliant grain of the best refined sugars of commerce. For a specimen of the *maple sugar* I was indebted to Mr. FARADAY; this, when I received it, was very impure and deliquescent, but by treating it by the process above alluded to, a portion was separated that differed but little in its appearance from cane sugar. The *beet-root sugar* was made and refined in France;

* In these results *fixed* bodies only have been allowed for, and those marked (v), as occurring in commerce, are probably subject to slight variations in their composition.

it was perfectly white, but rather soft and fine in the grain. The *East India moist sugar* was of a very low kind, and known in commerce by the name of *Burdwan sugar*; it was deprived of its hygrometric moisture before analysis by exposure to sulphuric acid under a receiver. The *diabetic sugar* was prepared as above; the results given were obtained many years ago, and I have had no opportunity of repeating the analysis with the present apparatus; I believe however that diabetic sugars in general belong to the Honey variety. The *sugar of starch* was prepared by myself in the usual manner.

Of Amylaceous Principles.

Before we proceed to consider the analysis of amylaceous bodies, a few remarks on the nature of these and similar substances may not be deemed improper. It has been known from the very infancy of chemistry, that all organised bodies, besides the elements of which they are essentially composed, contain minute quantities of different foreign bodies, such as the earthy and alkaline salts, iron, &c. These have been usually considered as mere mechanical mixtures accidentally present; but I can by no means subscribe to this opinion. Indeed, much attention to this subject for many years past has satisfied me that they perform the most important functions; in short, that organization cannot take place without them. This point will be more fully investigated hereafter: at present it is sufficient merely to observe, that many of those remarkable changes which crystallized bodies undergo on becoming organized, are more apparent than real; that is to say, their chemical composition frequently remains essentially the same; and the only points of difference that can be traced, is the presence of a little more or less of water, or the intimate

mixture of a minute portion of some foreign fixed body. There is no term at present employed which expresses this condition of bodies, and hence, to avoid circumlocution, I have provisionally adopted the term* *merorganized*, (*μέρος pars vel partim*) meaning to imply by it that bodies on passing into this state become partly, or to a certain extent, organized. Thus starch I consider as *merorganized* sugar, the two substances having, as we shall see presently, the same essential composition, but the starch differing from the sugar by containing minute portions of other matters, which we may presume, prevent its constituent particles from arranging themselves in the crystalline form, and thus cause it to assume totally different sensible properties.†

* I am indebted to my friend Mr. LUNN for this term.

† When this subject first occupied my attention many years ago, I was at a loss to form any notion of the *modus operandi* of these minute admixtures of foreign bodies, except the mechanical one mentioned in the text, viz. that they operated by being interposed, as it were, among the essential elements of bodies, and thus by weakening or modifying their natural affinities. But the admirable Paper, published by Mr. HERSCHEL, in the Philosophical Transactions for 1824, "On certain motions produced in fluid conductors when transmitting the electric current," appeared to throw an entire new light on the subject. The facts brought forward in this Paper are of the most important kind, and seem to me to be evidently connected with a principle of a more general character, which when completely developed, will lead to the most unexpected results. "That such minute proportions of extraneous matter," says Mr. H. "should be found capable of communicating sensible mechanical motions and properties of a definite character to the body they are mixed with, is perhaps one of the most extraordinary facts that has yet appeared in chemistry. When we see energies so intense exerted by the ordinary forms of matter, we may reasonably ask what evidence we have for the imponderability of any of the powerful agents to which so large a part of the activity of material bodies seem to belong?"

Any substance may be supposed capable of performing the part of a merorganizing body; but, in a certain point of view, *water* appears to constitute the *first and chief*, at least in organized substances.

Wheat Starch. The most perfect form of the amylaceous principle is undoubtedly that derived from wheat. This has been analysed by different chemists with very different results. MM. GAY LUSSAC and THENARD state that they found it to contain as much as 43·55 per cent. of carbon ; while Dr. URE informs us that he only found 38·55 per cent. The following observations will sufficiently explain these differences.

A very fine specimen of wheat starch, which had been prepared expressly at my desire without the addition of the colouring matter commonly added to the starch of commerce, and which had been kept in a dry situation for many months, was found, in the ordinary columnar form in which it usually occurs, (abstracting foreign matters) to consist of

Carbon 37·5

Water 62·5.

One hundred parts of the same specimen reduced to a state of fine powder, and subjected to a temperature between 200° and 212°, for the space of 20 hours,* lost, in a mean of two experiments, 12·5 parts, and on being analysed in this state gave

Carbon 42·8

Water 57·2,

which very nearly coincides with what by calculation it ought to have given, on the supposition that the loss of weight was owing to the escape of water, a circumstance indeed of which there could have been little doubt. Starch however in this state still retains water, a portion of which may be separated

* I have reason to believe from other experiments that six or eight hours, or even less, of steady exposure to the boiling temperature, will sometimes reduce both starch and arrow root, and even gum, to this state of desiccation.

by subjecting it to higher temperatures. Thus, after having been exposed as above for 24 hours to the temperature of 212° , on being further submitted to a temperature between 300° and 350° for six hours longer, it lost 2·3 per cent. more, and analysed in this state gave very nearly

Carbon 44

Water 56.

It had now acquired a slight yellow colour, and seemed to have suffered some change in its properties; hence, this is probably nearly the utmost quantity of water that starch is capable of parting with, short of decomposition.

Arrow root. This is another variety of the amylaceous principle, of which, like sugar, there seems to be a great variety. The specimen on which the following experiments was made was remarkably fine, and free from adventitious matters. It had been kept in the same drawer with the starch before mentioned, and under precisely similar circumstances of the atmosphere was found to consist of (abstracting foreign matters)

Carbon 36·4

Water 63·6.

One hundred parts, in the above state, exposed for twenty hours to a temperature between 200° and 212° , lost fifteen parts. Hence its composition, when thus dried, was very nearly the same as that of wheat starch similarly exsiccated; or it consisted of

Carbon 42·8

Water 57·2.

On being subjected to the full temperature of 212° for six hours longer it lost 3·2 per cent. more, and was then reduced

to a state similar to that of starch dried between 300° and 350° , or it consisted very nearly of

Carbon 44.4.

Water 55.6.

When subjected to the temperature of 300° and 350° for six hours longer, it lost 1.38 per cent. more of its weight, but became of a deeper yellow colour than starch similarly exposed, and consequently shewed greater marks of decomposition. Hence, this form of the amylaceous principle, like the sugar of honey before-mentioned, seems to part with the whole of the water not essential to its composition at the temperature of 212° , or even perhaps below this point if exposed for a period sufficiently long.

It may not be deemed superfluous to notice here very briefly two or three circumstances resulting from the above analyses, which, though their importance may not be seen at present, should be constantly borne in mind, as they will enable us hereafter to throw light on many points connected with organization, which otherwise would be inexplicable.

In the first place, the identity of composition between the sugar of honey and arrow root, under the ordinary circumstances of the atmosphere, seems to show that the differences among the varieties of the amylaceous principles are precisely analogous to those existing among sugars, or in other words, that there are *low* starches as well as *low* sugars. Whether arrow root be the lowest that exists, I am unable to say; but I have met with none lower; and have reason to believe that the greater portion of the other varieties of the amylaceous principle known to exist, like the varieties of sugars above given, are intermediate in their composition between arrow

root and wheat starch. The same remarks apply to other merorganized principles.

In the second place, the identity of composition between wheat starch and cane sugar, and between the sugar of honey and arrow root above mentioned, seems to show that, though merorganized bodies are not actually capable of assuming the crystalline form, yet that the original tendency among their essential elements to combine in certain proportions (and perhaps to assume certain forms) still continues to operate, though in a mitigated degree, and thus to exert, as it were, a feeble *nisus*, or endeavour toward the maintenance of certain definite modes of existence.

Thirdly, and lastly, crystallized bodies usually part with their water of crystallization with difficulty, and when they do, it is commonly *per saltum*, or in definite quantities. Merorganized bodies, on the other hand, retain water so feebly at all points, that within certain limits this fluid may be readily separated, or made to combine with them in every proportion. And this appears to be true, not only with respect to water, but with other substances capable of combining with merorganized bodies. It may be remarked also in general, that *low* varieties of principles resemble merorganized bodies in these and some other respects; thus, they usually part readily with all the water not essential to their composition at the temperature of 212° , or even less (provided they be submitted to it long enough,) above which point they rapidly undergo decomposition, &c.

Lignin, or the woody fibre.

Messrs. GAY LUSSAC and THENARD first showed that the hydrogen and oxygen in this principle exist in it in the proportions in which they form water, a result fully confirmed by my experiments. The variety of forms in which lignin occurs in different woods is so great, that an examination of them all would be quite out of the question; I therefore selected two, *viz.* the woods of the *Box* and *Willow*, which appeared to present the greatest contrast; the one being among the densest, the other the lightest of the woods. These were both treated exactly in the same manner, that is to say, they were first reduced to the form of a coarse powder by rasping, then well pulverized in a WEDGWOOD mortar, and afterwards sifted. Being by these means reduced to the form of impalpable powders, they were boiled in repeated portions of distilled water till that fluid came off unchanged: a tedious process, requiring several days to accomplish perfectly. After this they were similarly treated with alcohol, and finally again with distilled water. They were now exposed to the atmosphere, when in a dry and favourable state; and when they ceased to lose weight were submitted to analysis, and found to consist of (abstracting foreign matters)

	Box.			Willow.		
Carbon	-	42.7	- - -	-	42.6	
Water	-	57.3	- - -	-	57.4	

A known weight of each was then exposed for twenty-four hours to a temperature of 212° , and afterwards for six hours longer (by means of an oil bath) to a temperature between

300° and 350° ; and at the end of this time they were found to have lost, per cent.

Box.	Willow.
14·6	14·4

Analysed in this state of desiccation, they were found to consist of

	Box.	Willow.
Carbon - - -	50·0	49·8
Water - - -	50·0	50·2

showing that the loss of weight arose from the escape of water. These latter results nearly agree with those of MM. GAY LUSSAC and THENARD, as obtained from the analyses of the woods of the *Oak* and *Beech*, and seem to show beyond a doubt, that the composition of all of them is similar, or that they consist of equal weights of carbon and water ; to which simple analogy this important principle probably owes its stability.

Lignin undoubtedly exists in many other forms besides the woody fibre ; indeed it appears to constitute the skeleton or ground work on which most organic processes in the vegetable kingdom are carried on. To illustrate its properties as an *aliment*, the only point of view in which we have to consider it here, I shall briefly quote the experiments of Professor AUTENRIETH of Tübingen, who showed some years ago, that by proper management this principle might be rendered capable of forming bread. The following was the method he employed for this purpose. In the first place, every thing that was soluble in water was removed by frequent maceration and boiling. The wood was then reduced to a minute state of division, that is to say, not merely into fine fibres,

but actual powder ; and after being repeatedly subjected to the heat of an oven, was ground in the usual manner of corn. Wood thus prepared, according to the author, acquires the smell and taste of corn flour. It is however never quite white, but always of a yellowish colour. It also agrees with corn flour in this respect, that it does not ferment without the addition of leaven, and in this case sour leaven of corn flour is found to answer best. With this it makes a perfectly uniform and spongy bread ; and when it is thoroughly baked, and has much crust, it has a much better taste of bread than what in times of scarcity is prepared from the bran and husks of corn. Wood flour also, boiled in water, forms a thick tough trembling jelly, like that of wheat starch, and which is very nutritious.*

It may be remarked that all the preceding principles are capable of being converted into oxalic acid by the action of the nitric acid, and into sugar by the action of dilute sulphuric acid.

Acetic Acid, or Vinegar.

This principle seems to have been more or less used as an aliment, either by accident or design, in every age and country. There have been various analyses of it published, by different chemists ; but it is singular, that although some of them have given its exact composition, no one seems to have been struck with the most remarkable peculiarity of its composition,† viz.

* See the Edinburgh Magazine for November 1817, p. 313, where an account is also given of the Lapland mode of making bread from the bark of trees, as described by VON BUCH. It is not improbable that during the above processes the lignin combines with water, and forms an artificial starch.

† BERZELIUS, in his Paper On the definite proportions, in which the elements

that the hydrogen and oxygen exist in it in the proportions in which they form water. Some experiments which I made many years ago appeared to render this probable, but from the difficulties attending the analysis of this acid, and the uncertainty arising from the properties of the oxide copper formerly stated, I was unable to satisfy myself completely on the subject. On repeatedly burning, however, a very fine specimen of the acetate of copper, in a given bulk of oxygen gas, with the apparatus described at the commencement of this Paper, it was found that the volume of the gas underwent no change, and hence, that the above opinion was correct.

Acetic acid, freed from non-essential water, I find to be composed of

Carbon 47·05

Water 52·95,

results which almost exactly agree with those of other chemists.

Sugar of Milk.

The sugar of milk employed in these experiments was prepared by myself in the usual manner, and rendered as pure as possible by repeated crystallizations. It was then freed from its hygrometric moisture by confinement under a receiver with sulphuric acid, and was found to consist of

Carbon 40

Water 60,

results almost exactly agreeing with those of BERZELIUS.

of organic nature are combined, assigns to vinegar this composition. See *Annals of Philosophy*, v. 174 (O. S.) Dr. THOMSON also, in the last edition of his *Chemistry*, gives the same composition; though in his more recent work he has assigned to it another proportion of hydrogen.

Manna Sugar. The saccharine principle existing in manna has been long known to possess peculiar properties. That employed in the following analysis was separated by means of alcohol in the manner commonly described in chemical books, and was obtained in a state of perfect purity by repeated crystalizations from that fluid. It was then dried at 212° , and in this state was found to consist of

Carbon 38·7

Water 61·3

results very different from those of M. THEODORE DE SAUSURE.* This sugar seems to part with hygrometric water only at the temperature of boiling water; but a few degrees above this point it begins to suffer decomposition, and at 250° it assumes, without melting, the form of a brown powder, and acquires a strong empyreumatic odour.

Gum Arabic. A very fine specimen of gum arabic reduced to powder, and analysed as it existed under the ordinary circumstances of the atmosphere, was found (abstracting foreign matters) to consist of

Carbon 36·3

Water 63·7.

One hundred parts of the same gum, exposed to a temperature between 200° and 212° , for upwards of 20 hours, lost 12·4 parts. Hence its composition thus dried would be nearly

Carbon 41·4

Water 58·6.

Results confirmed almost exactly by actual analysis.

The same gum, further exposed to a temperature between 300° and 350° for six hours longer, assumed a deep brown

* See Bibliothèque Britannique, 1814; also Annals of Philosophy, vi. 424.

colour, and seemed to have suffered decomposition, though it lost in weight only 2·6 per cent. more. Hence, gum probably parts with the whole of the water not essential to its composition at the temperature of 212°, provided it be exposed for a sufficient time to this degree of heat.

Substances belonging to this series appear in general to be of a weak or *low* kind, though they are probably very numerous. They may be readily distinguished by being converted into sacclactic acid by the action of nitric acid.

The vegetable Acids.

Oxalic acid. Many years ago I ascertained that this acid in the crystallized state consists of

Carbon 19·04
Water 42·85
Oxygen 38·11,

a composition assigned to it long since by other chemists, and now I believe generally admitted, except by Dr. THOMSON, who informs us that he has met with a specimen containing as much as half its weight of water.* I have examined a great many specimens with the view of verifying this result, but hitherto have not been successful.

Citric acid. This and all the following acids, except the *malic*, were analysed at the same period as the oxalic acid above mentioned, and the results have been recently verified. I find the crystals of citric acid to consist of

Carbon 34·28
Water 42·85
Oxygen 22·87.

* Attempt to establish the first principles of chemistry by experiment, ii. 103.

This composition has been approached very nearly by several chemists; but no one, so far as I know, has given it exactly.

Tartaric acid in crystals is composed of

Carbon 32.0

Water 36.0

Oxygen 32.0,

a composition assigned to it by Dr. THOMSON in his work just quoted.

Malic acid. I am not acquainted with any analysis of malic acid except that of M. VAUQUELIN,* which has not, I believe, obtained much confidence among chemists, chiefly on account of the large proportion of hydrogen which he assigns to it. The acid I employed was obtained from the berries of the mountain ash by a process very similar to that of Mr. DONOVAN. It was not analyzed *per se*, but in combination with lead, with lime, and with copper, and was found, abstracting water not essential to its composition, to consist of

Carbon 40.68

Water 45.76

Oxygen 13.56,

This acid, in many points of view, may be regarded as one of the most interesting and important of all the vegetable acids.

Sacclactic acid. The unexpected composition of this acid induced me to investigate its properties more fully than I had otherwise intended. What I first employed was obtained from the sugar of milk, and hence was tolerably pure, though not perhaps completely so. Latterly, I have preferred that

* Annales de Chimie et de Physique, vi. 337.

prepared from gum, which, though exceedingly impure as first obtained, may be easily and completely purified by the following simple process.

Add ammonia in slight excess to the impure acid, and afterwards as much boiling distilled water as will dissolve the sac lactate formed. Filter the solution while boiling hot, and then evaporate it very slowly nearly to dryness. The sac lactate of ammonia will be separated in the form of crystals, which are to be washed with cold distilled water till they become quite white and pure. They are now to be again dissolved in distilled water, and the boiling saturated solution permitted to drop from a filter into cold diluted nitric acid. This latter of course decomposes the sac lactate, and precipitates the sac lactic acid in a state of perfect purity. Thus obtained, this acid was found to consist of

Carbon 33.33

Water 44.44

Oxygen 22.22

results differing a little from those of other chemists, who probably did not take the necessary pains to obtain this acid in a perfectly pure state.

In conclusion, I wish to observe, that I purposely abstain at present from making any further observations on the preceding results than those already given. I do this for several reasons: in the first place, such observations will appear with greater effect, when the whole of the facts in my possession are laid before the public; and secondly, I consider that data which lead to such important conclusions

as these appear to do, cannot be too firmly established; I therefore, in the mean time, earnestly invite chemists in general to repeat them, and thus either to confirm them, or point out their errors; and for the sake of those who may be inclined to take this trouble, I shall close this part of the subject with the following remarks: 1. The multiples of hydrogen, carbon, and oxygen, are assumed in the preceding calculations as 1 : 6 : 8. 2. The results given are, on all essential points, the means of many experiments, the differences among which are either inappreciable, or at most vary from .01 to .03 of a cubic inch in from 5 to 8 cubic inches of carbonic acid or oxygen gas; the greatest differences in general, being for obvious reasons, found among mercurialized bodies; and hence the analyses of these are usually stated to the first decimal figure only. 3. As rules to be observed, I would say, that a single result should never be registered, nor a single calculation made, till the operator has made himself complete master of his apparatus, and carefully studied the nature of the substance to be analyzed; for different substances often require very different management: that two or three results should never be relied on; the minute quantities here sought can be only obtained, like those of astronomy, by repeated observations: and lastly, the utmost care should be taken that the substances operated on be *pure*, a point of greater importance, and frequently of more difficult accomplishment than any other, and one that has caused me more trouble than all the rest put together.